Renfrew Close Rain Gardens – Year two monitoring and project evaluation report, May 2017.

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Cover image: Basin 2 during rainfall simulation ©UEL.

Executive summary:

- This report presents results obtained from the second year of monitoring, covering the period of April 2015 – March 2017, and comments on the basin performance and lessons learned over the two years of the project.
- The research has been conducted over a two-year period by the Sustainability Research Institute at the University of East London (UEL) on behalf of the Environment Agency.
- Further results can be found on the project website, which can be accessed here: http://renfrew-rain-gardens.weebly.com/.
- During this monitoring period Basins 2 and 4 attenuated all the water received before any pressure readings could be obtained due to rapid infiltration. A pattern seen across the two years of monitoring.
- The pattern of large lag times between peak rainfall and peak pressure observed in the first year of monitoring continued for almost all rain events observed in Basin 1 during the second year; with an average delay of 13.2 hours for the first rain event observed during each rain event period.
- A one hour rainfall simulation has been carried out for Basin 2 (1 in 100-year event) and Basin 4 (1 in 10-year event), the results revealed rapid infiltration of water following surface pooling. Because of this, we hypothesise that the large lag times between peak rainfall and peak pressure seen in Basin 1 are caused by poor connectivity between that basin and its catchment area.
- A Thames Water V notch weir on the overflow outlet from Basin 4 acts as a proxy for the site outflow. The data from this confirms that no water has left the site from this SuDs feature since installation. Furthermore, during and after the rainfall simulation this data demonstrates that no water left the site, even after such large events.
- It can be concluded that the Rain Garden Basins are performing as intended –as they enable complete infiltration of diverted rain water from the impermeable surfaces at Renfrew close, reduce the impact of rainwater from the estate on the TW sewer network and hold the rainwater in the rain garden system for long lag times before rainwater is infiltrated successfully.
- The headline figure is that over the two years of this project, some 746,283 Litres (nearly ¾ million Litres of water!) have been attenuated by these rain gardens, proving that retrofit SuDs projects using infiltration can be very effective at reducing the rainwater burden on the sewer network.
- Finally, due to the successes shown by the Renfrew Gardens rain garden system, Newham council are encouraging a wider roll out of rain garden retrofit projects across the borough. Several new rain gardens being planned at present.

Introduction:

The Renfrew Close rain gardens are a community scale, sustainable drainage (SuDs) scheme, in the London Borough of Newham. This was the first large scale retrofit of a raingarden in the borough and was implemented through a partnership consisting of the Environment Agency, the London Borough of Newham, Groundwork London and Thames Water. The Sustainability Research institute at UEL has monitored the hydrological performance of the rain gardens over two years.

The report presents results obtained from the second year of monitoring, covering the period of April 2015 – March 2017, and comments on the basin performance and lessons learned over the two years.

Design:

The rain gardens have been designed (with input from Robert Bray Associates) to accommodate rainfall from a variety of rain events to prevent surface level flooding. The series of rain gardens are shown in Figure 1 below:

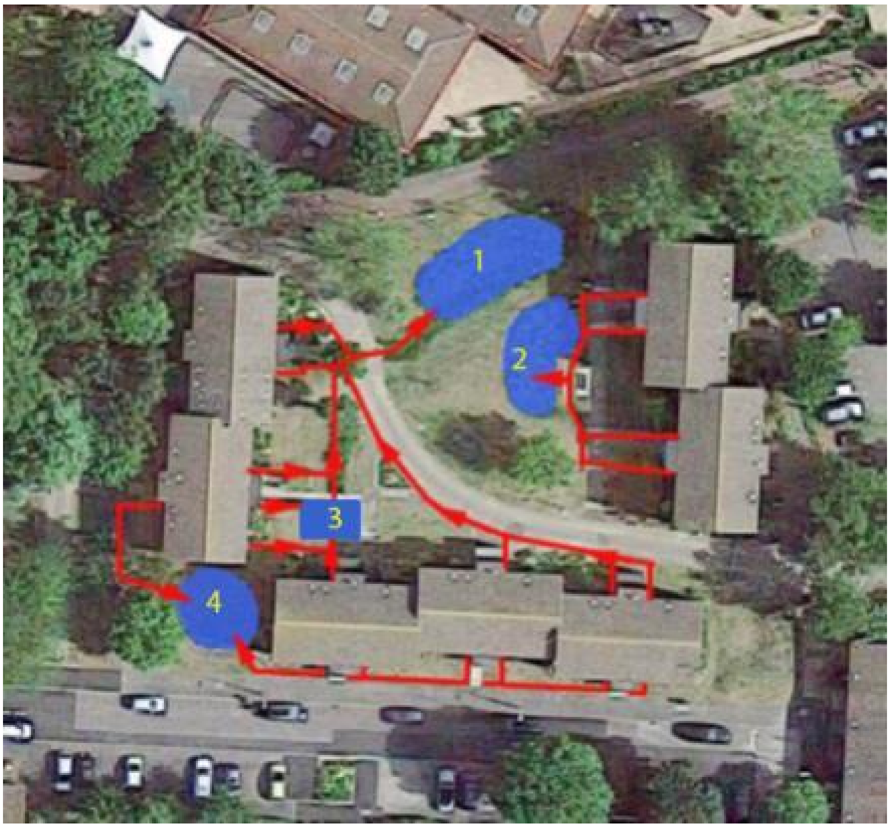


Figure 1: The Renfrew Rain gardens layout with red lines highlighting the flow of water into the basins. Image source: Google Maps.

Basin 1 and Basin 4 are designed to attenuate rainfall for a 1 in 10-year return period.

Basin 2 is designed to attenuate rainfall for a return period of 1 in 100 year, with a 30% allowance for climate change. This Basin also contains a smaller 1 in 2-year central basin.

Basin 3 is not being monitored as this is used for a community garden.

The rain gardens receive water from hard surfaces at roof and ground level as well as receiving water from soft surfaces at ground level. It is estimated from original design plans that the run off from 750m² of roof area and 165m² of road area is diverted into the rain gardens. These area figures must be caveated as site visits have revealed:

1. There are areas of ponding on the road area during rain events.
2. The ground level gulley for the road is broken and disjointed so not all water flows to the rain basins.
3. That a number of the vegetated channels leading to the rain gardens are unlined so there will be water lost to infiltration and evapotranspiration.

Monitoring:

The rain garden system is being monitored in several ways. There is a locally mounted weather station which provides accurate information on precipitation and other factors. Water input from roof level is observed using inline flow meters connected to the downpipes from roofs that feed into Basin 2 and Basin 4. Finally, there are pressure sensors in basins 1, 2 and 4 which allows for investigation into how the rain gardens react to rainfall events.

The weather station and pressure sensors are equipped with telemetry systems allowing for remote data capture, whilst the more accessible flow meters capture data and are manually downloaded using data loggers.

Results and Discussion:

Here are some of the results gathered during the second year of monitoring. Most rain event analysis graphs are found on the project website, which can be accessed here: http://renfrew-rain-gardens.weebly.com/

The second annual monitoring period ran from April 2016 to March 2017. The data gathered by the Renfrew Close weather station reveals that this monitoring period had a greater number of rainfall days but received a lower total rainfall, than the long-term average for London for the same period.

The maximum temperature experienced at the site was also greater in every month monitored compared to the long-term average during this period which may have influenced rainfall volumes.

Table 1: Second year monitoring period, weather summary:

Month	Rainfall days	Total monthly rainfall (mm)	Maximum temperature (°C)	Long term average rainfall days	Long term average rainfall (mm)	Long term maximum temperature (°C)
Apr-16	18	30.2	18.3	9	40.1	14.6
May-16	9	48.4	28.4	9.2	44.9	18.1
Jun-16	22	86.2	27.2	7.4	47.4	21
Jul-16	13	14.8	34.5	6.3	34.6	23.4
Aug-16	3	0.8	34.4	8.1	54.3	23.1
Sep-16	8	7.4	34.7	8.6	51	20

Oct-16	7	21.8	21.5	10.9	61.1	15.5
Nov-16	15	62.7	16	10.9	57.5	11.3
Dec-16	5	5.1	14.9	9.5	48.4	8.4
Jan-17	10	50.8	11.6	11.4	41.6	8.1
Feb-17	13	25	17.4	8.5	36.3	8.6
Mar-17	6	11.4	21.6	9.8	40.3	11.6
Totals	129	364.6	-	109.6	557.5	-

* Long term average source: Met Office 2016.

August 2016 had the lowest rainfall total during the monitoring period to date with just 0.8mm of rain, and June 2016 had the highest total rainfall during the monitoring period with 86.2mm of rain. Table 1 reveals that these total volumes are quite low compared to the long-term averages (35% lower).

Basin performance:

As mentioned in previous reports, Basin 1 has provided the most data for analysis, it receives water from a catchment area of 369.6m^2 (an area made up of 4 half roofs, and the road area as seen in Fig.1.) which is conveyed via a road gulley, and a reverse fall channel under the road.

Throughout the second annual monitoring period, delays between peak rainfall and peak pressure have been consistently recorded in Basin 1. The data collected from the largest three rainfall events each month reveals that there is an average delay of 13.2 hours between peak rainfall and peak pressure in Basin 1.

Interestingly across the whole monitoring period Basin 2 and Basin 4 which are monitored identically, have provided few data. The loggers are functioning and recording as normal, suggesting that most recorded data for Basin 2 and Basin 4 is below the lowest observable unit of measurement achievable by the pressure sensors (0.01 Bar). This is likely due to the low rainfall volumes, the caveats surrounding impermeable areas and perhaps most significantly large interception and infiltration during conveyance of water to these basins.

Using the total area of hard surfaces as provided by the landscape architects for the scheme, Robert Bray associates, a calculated maximum volume of water attenuated by the rain gardens and diverted from the original site sewer (i.e. the volume that is attenuated by the rain gardens) can be calculated.

The largest rainfall event over 24 hours during the monitoring period occurred on the 23rd June 2016 and was completely attenuated!

The largest event of the final year of monitoring at 24.2mm is comparable to the largest observed during the monitoring in the first year of monitoring year (April 2015 – March 2016) which totalled 24.6mm. The rainfall on June 23rd 2016 caused widespread flooding across the Southeast of England and was widely reported by national newspapers, Renfrew Close experienced no such problems.

http://www.telegraph.co.uk/news/2016/06/23/uk-weather-storms-light-up-the-skies-as-rain-and-floods-expected/

https://www.theguardian.com/uk-news/2016/jun/23/torrential-rain-and-flooding-in-london-and-south-east-on-referendum-day

A summary of the size of the top 3 rainfall events for each month during the monitoring period is shown in Table 2 below:

Table 2: Rainfall depth categories and the number of Top 3 daily rainfall events observed.

Rainfall depth	Number of events observed in Top 3 monthly rain events
1-5mm	13
6-10mm	7
11-15mm	0
16-20mm	4
>20mm	2
Total:	26

As seen in Table 2, there were very few rainfall events observed during the second monitoring year that were greater than 15mm leaving the Basins unchallenged in terms of attenuating a large rain event like that of a 1 in 100-year storm across a variety of durations 1 hour (40mm), 6 hour (60mm).

Like other studies many the largest 3 rainfall events per month observed over the monitoring period were lower than 25mm (Alves *et al.,* 2014) furthermore a high percentage of the rainfall events presented here are under 10mm or less (20/26).

Nonetheless during the entire monitoring period to date (April 2016 – March 2017) all the rain falling on the site as shown in Table 1 has been retained by the rain gardens. Caveats permitting, this amounts to the attenuation of up to 333,609 Litres of water in the second year of monitoring.

The total amount of water attenuated by the Renfrew rain gardens during the overall two-year monitoring period was 746,283 Litres (nearly ¾ million Litres of water!)

Rainfall simulation:

As there had been no rainfall events nearing the designed capacity of the rain gardens by the end of the two-year monitoring period, a rainfall simulation event was designed and carried out in May 2017 to proof test the performance of the rain gardens under extreme conditions.

Similar stress testing has been undertaken previously by Thames Water on a small-scale SuDS project (Ashby Grove) with great success (Alves *et al.*, 2014). And has been carried out on two estates in the London Borough of Hammersmith by UEL for another monitoring project with very successful outcomes (Connop *et al.*, 2016).

> *The aim of the simulation was to mimic the inflow of a 1 in 100-year rain event and a 1 in 10-year rain event (over a 1 hour period) in two rain garden basins to judge the performance of the installed SuDS features. Basins 2 and 4 were selected for this test.*

The Environment Agency provided finance for the test. Whilst a water tanker supplying final stage effluent (treated wastewater) was supplied by BP Mckeefrey following financial support from Thames Water. Newham council provided temporary fencing on the day of the test to aid with Health and Safety concerns. Finally, members of UEL staff carried out the test with the assistance of an internship student from Thames Water.

Methods:

The volume of water required was calculated as in Table 3 below:

Table 3: Calculated volumes required during testing.

SuDS system	Design spec.	Catchment area (m^2)	rainfall depth for simulation of event in 1 hour (mm)	Maximum water received in 18mm, 1 in 5-year event over 1 hour (Litres)
Basin 2	1 in 100-year event	136.37	40	5454.8
Basin 4	1 in 10-year event	272.72	22	5999.84

On site:

1. The Pressure sensors in Basins 2 and 4 were updated so that they recorded pressure at every minute.
2. The water tanker stilling tube was calibrated into approximately 1000L increments.
3. The appropriate amount of water was then released into the basins in approximately 1000L increments evenly over one hour.
4. The pressure sensors recorded the pressure change in the basin over time during and after the test.

Images of Test:

Basin 2 rainfall simulation:

Figure 2: images from Basin 2 rainfall simulation. Top left– Tanker hose feeding into Basin 2, Top right, Water being poured into Basin 2, Bottom: Pooling surface water in Basin 2 at end of test.

Basin 4 rainfall simulation:

Figure 3: images from Basin 4 rainfall simulation. Top – set up showing tanker feeding hose into Basin 4, bottom left, water being poured into Basin 4, Bottom right, water pooling in Basin 4 at end of test.

Basin 2 - results

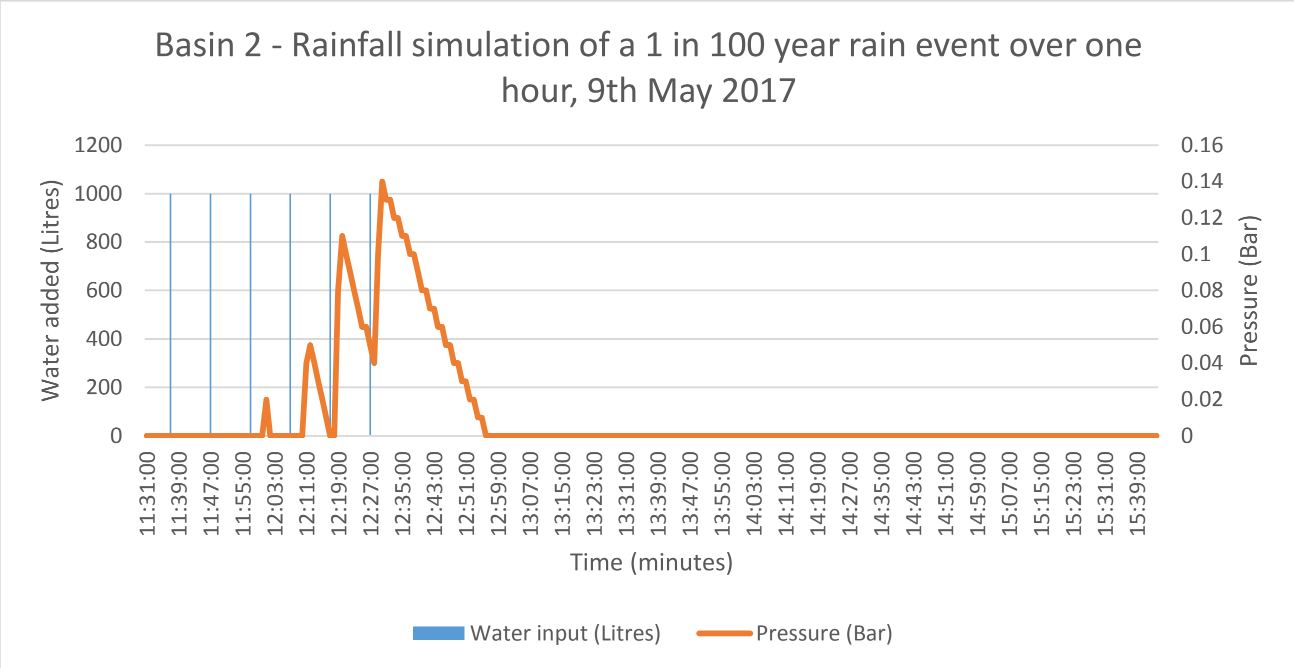


Figure 4: Basin 2, 9th May 2017 rainfall simulation; Water input and Pressure against time.

Test information:

Basin 2 - Rainfall simulation test data	
Time Water applied	Volume (Litres) approximate.
11:37	1000
11:47	1000
11:57	1000
12:07	1000
12:17	1000
12:27	1000

Visible water pooling in rain garden basin:

Basin 2 - Rainfall simulation test, visible pooling data in centre of basin	
Time	Visible pooling depth (cm)
12:32	16
12:51	8
13:10	0

Basin 2 had a delay of 26 minutes between the final water input at 12:27 and the pressure in the Basin falling to 0 Bar at 12:56. Following the conclusion of the water input during this rainfall simulation, there was visible pooling in the basin with a depth of 16cm, this was recorded at c.20 minute intervals, with the depth of water pooling being recorded as 0cm after 40 minutes.

Basin 4 – results

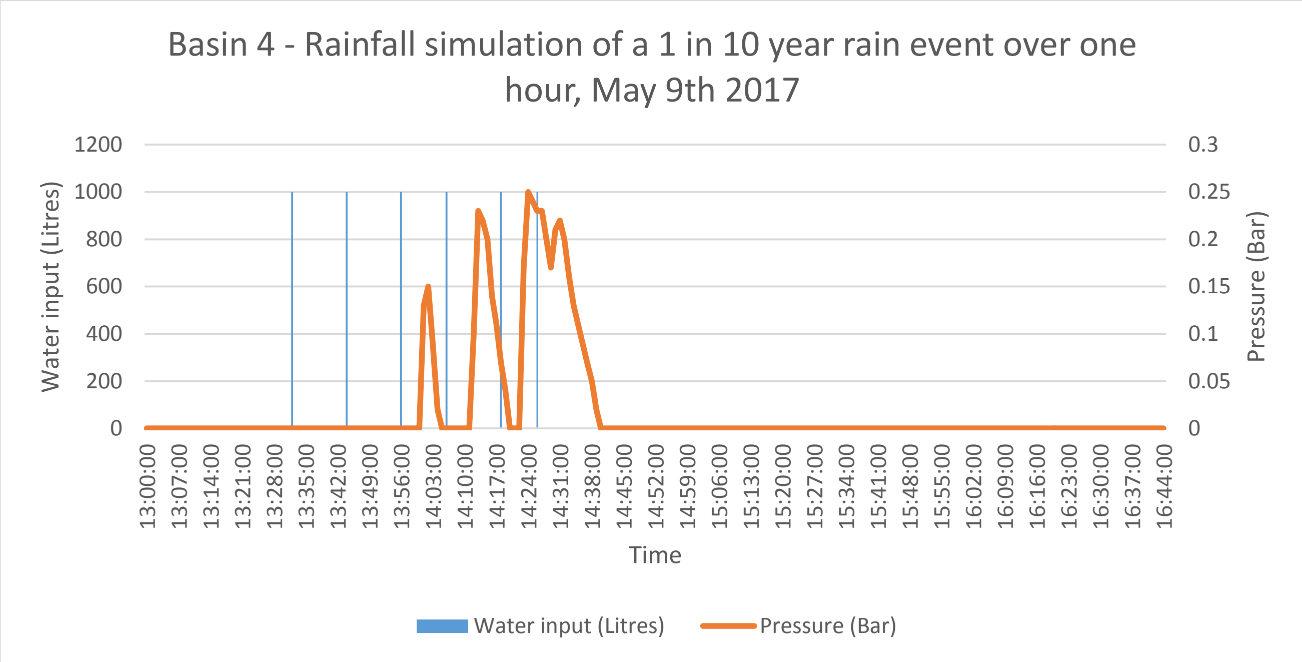


Figure 5: Basin 4, 9th May 2017 rainfall simulation; Water input and Pressure against time.

Test information:

Basin 4 - Rainfall simulation test data	
Time Water applied	Volume (Litres) approximate.
13:32	1000
13:44	1000
13:56	1000
14:06	1000
14:18	1000
14:26	1000

Visible water pooling in rain garden basin:

Basin 4 - Rainfall simulation test, visible pooling data in centre of basin.	
Time	Visible pooling depth (cm)
14:27	4
14:29	2
14:32	0.5
14:34	0.2
14:36	0.2
14:38	0

Basin 4 had a delay of 15 minutes between the final water input at 14:26 and the pressure in the Basin falling to 0 Bar at 14:41. Following the conclusion of the water input during this rainfall simulation, there was visible pooling in the basin with a depth of 4cm. This was recorded more intensely than Basin 1, and the depth of water pooling was recorded as 0cm after just 11 minutes.

Discussion:

Error discovered:

Following the rainfall simulation at Renfrew a clerical error surrounding basin labelling in the telemetry data was discovered. This has resulted in a change of basin labelling and a subsequent change in explanation surrounding the reasons for large basin delays.

However, it is important to note that this error wouldn't have been discovered until a rainfall simulation of the basins as the timings for water input and the subsequent large spikes in basin pressure were necessary to determine this error.

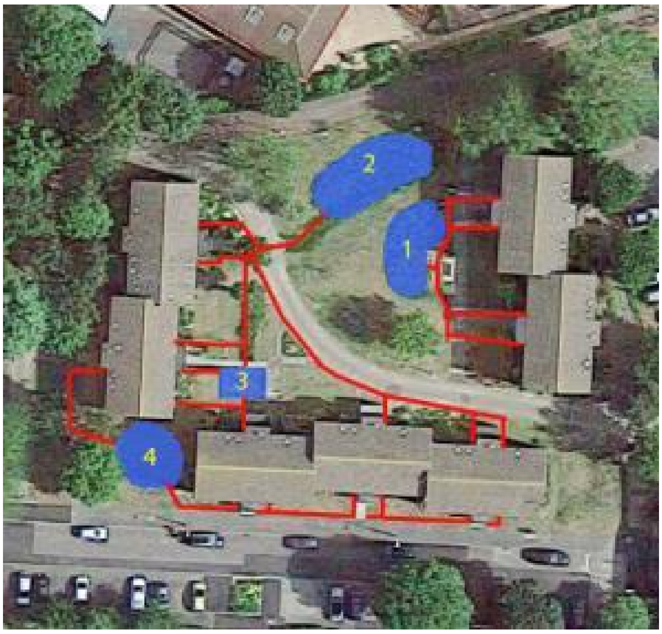
Implications:

The error does not change the fundamental result of the previous monitoring and rainfall simulation event – that all rain events including the simulated 1 in 100-year rain event have been successfully attenuated by the ran garden system at Renfrew close.

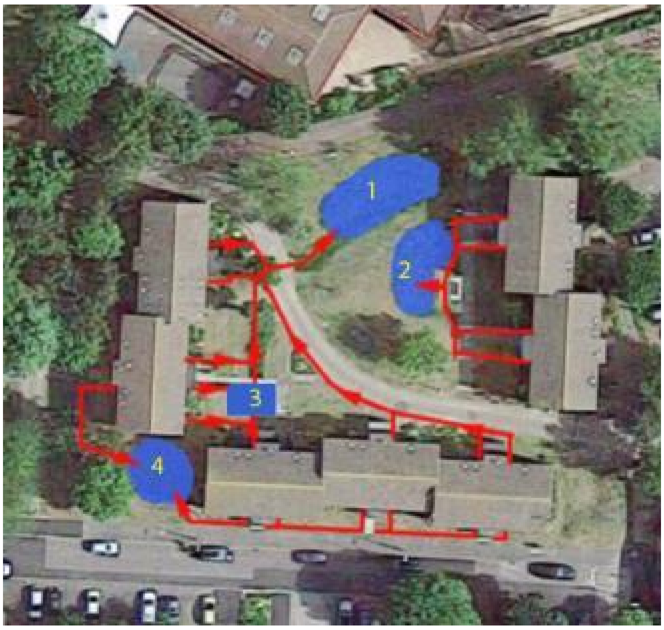
The site map with basin label diagrams has been relabelled to ensure the correct data is attributed to the correct basin. (See Figure 6)

The analysis performed on the data gathered by Basin 1 still stands, the data gathered shows long lag times between peak rainfall and peak pressure in the basin. However, the interpretation of this analysis and the reasons behind these lag times must now be revisited in previous reports.

Previous reports will be amended to include the new site map diagram, and descriptions and interpretation will be altered where appropriate. All data and labelling in this report is accurate and follows the new labelling seen below.



Left: Old basin labelling



Right: New basin labelling

Figure 6: Site map showing necessary changes to account for labelling ambiguity and subsequent data interpretation. New labelling on ***right***

General monitoring:

Throughout the entire two-year monitoring period, Basin 1 produced the most frequent data of the three rain basins being monitored. Basin 1 is a large rain basin designed to accommodate a 1 in 10-year rainfall event. Water is fed into this basin via existing rainwater gullies in the site access road, and through impermeable channels which divert rainwater to the rain garden through a specially designed reverse fall channel underneath the road.

Basin 2 and 4 have produced very little data over the last two years, despite Basin 2 being well connected to its catchment area and Basin 4 receiving water from a large catchment area.

Basin 2 has a shallow inner basin and a wider outer basin. And is fed by impermeable channels which divert water from roof level to the rain garden. Therefore, a rapid transfer from roof level to basin would be expected. However, during the rainfall simulation event it was observed that water infiltrates into the soil in the rain basin extremely rapidly– so rapidly in fact that infiltration would occur before being captured in the 15 minute intervals that the pressure sensor recording intervals were set at. During the rainfall simulation event the pressure sensor recording intervals were increased from 15 minutes to every minute, which increased data capture.

Basin 4 is a much larger basin with a bigger catchment area than Basin 2. However, rainfall from this catchment area is predominately conveyed to Basin 4 via unlined grass swales. These swales provide a greater opportunity for rainfall infiltration into the ground before reaching basin 4. For this reason, it is believed that most water, in all but the largest of rain events is attenuated through infiltration before entering the basin. In addition, it is likely that any water entering this basin is attenuated just as rapidly as rainwater being fed into Basin 2.

Why then has Basin 1 provided such consistent data, with such large delays (on average 13.2 hours, as seen on the webpage), if the soil is likely to be just as permeable as the soil in basins 1 and 4?

One interpretation may explain these large delays. The large delays observed in Basin 1 are most likely due to a slower input of water into this basin following a rainfall event. The gulley directing water from the road area is quite broken up and disjointed – frequent pooling occurs on this area (as mentioned in other reports).

Thus, the water from this road gulley may enter the rain garden over a long period as a trickle feed. Furthermore, the reverse fall channel that feeds rainwater into Basin 1 can easily be blocked with debris and litter which may delay the ingress of water further. This input of water over a long time could result in more data capture by the pressure sensor in Basin 1.

The delay between peak rainfall and peak pressure in Basin 1 shows how long the water is delayed by remaining within the SuDs system both at the surface and within the basin. Which is on average around 13.2 hours for the first rain event observed in one rain period and 21.8 hours for the second rain event observed during the same period. This is to be expected as successive events over a short time frame will cause water to exit the system via infiltration over a longer period as soil saturation is prolonged.

Interestingly some rain events were completely attenuated before displaying any positive pressure in Basin 1, suggesting the rain was attenuated completely by infiltration into the ground before soil saturation or pooling occurred.

Rainfall simulation:

The rainfall simulation provided a unique opportunity to test the rain gardens to their designed capacities.

During the testing, Basin 2 was tested first and received 6000L of water in one hour. This basin did not display any surface water pooling until around 3000L of water had been poured into the basin. This is highlighted in Figure 4, this pooled water reached a peak of 16cm deep after the final 1000L of water had been added which had fallen to 0cm after 38 minutes.

The depth of pooled water in Basin 2 was checked as often as possible whilst moving the tanker to Basin 4, so the actual time for the pooling to disappear is likely to have been shorter, for example following the last 1000l of water being added the pressure peaked at 0.14 Bar and took just 26 minutes to fall to 0 Bar (see Figure 4).

Basin 4 was tested second and received 6000L of water in one hour. Like Basin 2 this basin did not display any surface water pooling until 3000L of water had been poured into it. Following the input of the final 1000L of final stage effluent water, the pooled water took just 11 minutes to infiltrate away. The pressure peaked at 0.25 Bar and took just 16 minutes to fall back to 0 Bar (see Figure 5). This faster infiltration time compared to Basin 2 is likely due to the larger surface area of Basin 4.

The rain simulation results prove that rapid infiltration occurs in the rain basins at Renfrew close, allowing for attenuation of large rain events such as 1 in 10 or 1 in 100 year storms.

During the rainfall simulation, no water left the site, as recorded by the Thames Water V notch weir, which can be seen on the blog post about the rainfall simulation on the webpage.

A much greater depth of pooling of surface water would be required for overflow from Basin 4 to occur. Even at the 1 in 10-year return period over one hour Basin 4 was not full. In fact, Basin 4 demonstrated that it still had additional attenuation capacity remaining. This was also true for Basin 2 which despite having a large pool of surface water, also displayed that it had a much larger attenuation capacity remaining, as the basin was nowhere near maximum capacity.

Finally, the simulation results lend weight to the suggestion that over the 2-year monitoring period, rainfall is almost always infiltrated in Basins 2 and 4 before either pressure sensor readings can be generated or before soil saturation and surface pooling can occur.

In conclusion, the rainfall simulation at Renfrew Gardens confirms that the rain basins are performing as intended and designed.

Data uncertainties and limitations:

The total volume of water captured and retained by the rain garden system at Renfrew Close may have uncertainty introduced through the unquantified effect of infiltration, interception and evaporation of rainwater during conveyance from permeable surfaces to the rain garden system but these are beyond the scope of this study as they were not measured as part of the monitoring.

The pressure sensor equipment introduced limitations as the minimum value that can be recorded by the equipment is 0.01 bar, meaning values less than 0.01 Bar cannot be recorded.

Equipment error also could introduce inaccuracies into the data set. The weather station and pressure sensors are on telemetry based systems which could potentially increase the chances of data error during the transmission of data. The long-term radio error rate for the weather station is 0.5%, for the pressure sensor in Basin 1 and 2 it is 2% and for the pressure sensor in Basin 4 it is 29%. Radio error rate can introduce random errors in the data set by miscommunication or deformation of the data during data transfer.

Such errors arising from telemetry transmission were observed in the data set to a limited extent when data contained occasional readings that listed a record as a '*' symbol rather than a number. Following data cleaning the artefacts of these radio transmission errors can be seen to some extent in the analysed graphs on the webpage where pressure readings spike from a positive pressure reading down to 0 when they should (based on rain events) be recording a pressure value.

In terms of the rainfall simulation, it had always been intended that the rainfall simulation would take place during winter, the rationale behind this was that during the winter months the soil is more likely to be saturated, and represents the toughest test for the rain gardens. However due to delays the simulation was performed in May, after a very arid period; making the results more comparable to a summer test. Therefore, the results of the rainfall simulation may be generous as an indicator of all year-round performance, and performance may differ slightly in the winter. Although all data generated through the monitoring project to data suggests that winter performance is still adequate to have attenuated all rain events for both years of monitoring.

Key Monitoring lessons learned:

- The fixed-point camera used at Renfrew has posed a useful but limited addition. In the first year of monitoring, the battery life of the camera degraded too quickly to make telemetry a viable and reliable option for data transfer. During the second year of monitoring, the Camera was adjusted to record photos directly onto an SD card, with manual downloads performed. A vast number of photos have been generated, hosting these images online and analysing them takes a great deal of time and effort. Furthermore, some months have been lost due to battery or camera failure, and unexpected problems such as street lighting glare in the winter months have made photos unusable. Certainly, more time and cost effective methods could be developed.
- A remote weather station on a telemetry based system has allowed for efficient and user friendly data acquisition, and has been most useful for developing graphs and analysis from a single source point. However, this solution has resulted in its own problems – maintenance issues can be missed easily without care, and access arrangements are often slower than ideal, making the risk of data loss high. Future monitoring projects should make provision for maintenance checks and servicing of equipment.
- Similarly having the pressure sensors on a telemetry based system allowed for efficient and user friendly data acquisition. However, they were prone to battery failure due to poor mobile phone reception signals causing an increased power draw down which has resulted in a loss of data on occasion. Future monitoring projects if using telemetry systems should ensure that systems have either got back up power supplies, or are housed in areas of good reception to combat this increased power draw down.
- The use of magnetic flow meters was a first for UEL for downpipe monitoring, these have not been as useful as V notch gauges on other projects. This is primarily due to the increased sediment load from the roof catchment areas which clogs the flowmeter and sediment sump rapidly following a dry spell. Because of patchy data these haven't been used in the analysis of rainfall events. Future projects should attempt to either refine this method, or use alternative down pipe monitoring methods.
- A rainfall simulation is an essential monitoring tool – it allows for data to be generated that is unlikely to be observed and gathered naturally through a short monitoring period. Basin 2 and 4 were prime examples having recorded few data over the years. It may be a much more practical tool than long term monitoring when monitoring periods or project funding timescales are short.
- Having a V notch weir recording site outflow measurements, has provided a key source of data to double check against when monitoring the Rain gardens at Renfrew Close. This has been useful in confirming that no water has left the site when data or equipment failures have taken place. Future monitoring projects should include some sort of site outflow monitoring.
- Future studies should aspire to build in social research opportunities to understand people's enjoyment of SuDs features or provide methods for community feedback during the entire project lifetime, as these were not captured in this project.

Legacy of project:

From Newham council:

The London Borough of Newham has enjoyed supporting the Renfrew Close rain garden project. As the first project of its kind in the borough, the council was pleased with the strong community engagement at the design stage. The council is also pleased that the project has demonstrated just how effective rain gardens are at attenuating rainwater from hard surfaces through infiltration.

The project has also highlighted that a range of rain garden styles can be used to create places for nature, play and people making them versatile options that can be tailored to an area's needs. More importantly the project has shown that sustainable drainage systems (SuDs) can be installed successfully in pre-existing areas making them a valuable tool for rainwater management.

Following the positive results of the Renfrew Close rain garden project, the council is keen to increase the number of rain garden installations in the Borough. And are currently planning a number of additional rain gardens and SuDs projects in Newham.

From Thames Water:

Thames Water supports the installation of sustainable drainage systems to reduce the risk of flooding, as sewer flooding particularly in basements is a serious problem in parts of London. The installation of monitoring as an integral part of these SuDS pilot schemes will provide data that gives real world performance output and consequently will enable Thames Water to predict the effectiveness of sustainable drainage systems in such highly urbanised environments.

Conclusions:

- There have been very few large rainfall events during the entire two-year monitoring period. The long-term average values for monthly rainfall and maximum temperatures have consistently been exceeded in the last 24 months.
- The largest rain events for the second annual monitoring period were: summer – June 23rd 2016 and winter - January 12th 2017 have both been attenuated by the rain gardens.
- A rainfall simulation has revealed that there are rapid infiltration rates on site (11-26 minutes following a 1 in 10 and a 1 in 100-year rain event test respectively)
- The large lag times between peak rainfall and peak pressure recorded in Basin 1, are most likely due to poor connectivity between the catchment area and Basin 1.
- Some rain events in Basin 1 are attenuated through infiltration before a pressure increase is recorded indicating complete infiltration into the ground before soil saturation is reached.
- Basins 2 and 4 have attenuated all rain events observed during the monitoring project. The consistently generate few data, due to high interception and infiltration during conveyance of water to the basins and rapid infiltration within the basins.
- There have been no recorded instances of flooding from the Basins during the second year of study, suggesting all the water being directly fed into these areas has been attenuated amounting to a maximum amount of 333,609 Litres of water.
- **Key success:** The rain gardens have reduced the amount of rainwater flowing from permeable surfaces from Renfrew close into the TW sewer, reducing pressure on the TW sewer network.
- **Key success:** The rain garden project is showing that a retrofit SuDs project is a feasible option and can make a valuable contribution to water attenuation on existing sites and thus should be expanded to further sites.
- **Key success:** though not directly studied in this project, the rain gardens offer broader benefits such as enhanced biodiversity provision, enhanced aesthetics, and increased community use of the retrofitted space.
- **Key success** over the two years of the project 746,283 Litres (nearly ¾ million Litres of water!) have been attenuated by these rain gardens.
- **Key success:** Further dissemination of the project has been achieved through a susdrain case study (http://www.susdrain.org/case-studies/case_studies/renfrew_close_london.html)
- **Key success:** The London Borough of Newham is increasing the roll out of rain gardens across the borough following the success of the Renfrew Close Rain Gardens project.

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Many thanks to our project partners: